Discovery

Mineral chemistry and Geothermobarometry of intrusivecharnockitic rocks around Ikare, Southwestern Nigeria

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To Cite:
Oyeshomo AVA. Mineral chemistry and Geothermobarometry of intrusivecharnockitic rocks around Ikare, Southwestern Nigeria. *Discovery* 2024; 60: e13d1421
doi: https://doi.org/10.54905/disssi.v60i334.e13d1421

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Peer-Review History
Received: 12 January 2024
Reviewed & Revised: 16/January/2024 to 23/March/2024
Accepted: 27 March 2024
Published: 30 March 2024

Peer-Review Model
External peer-review was done through double-blind method.

Discovery
pISSN 2278–5469; eISSN 2278–5450

ABSTRACT

Charnockite of igneous origin outcropping around Ikare area, southwestern Nigeria have been investigated in this work. Two representative samples of the intrusive charnockites were prepared into thin and polished sections for petrographic and electron micro-analysis to determine their mineralogy and mineral chemistry. The mineral assemblages observed were quartz, plagioclase feldspar, alkali feldspar, orthopyroxene, clinopyroxene, hornblende and biotite while the accessory minerals are apatite, zircon, ilmenite, magnetite and opaque ores. Electron microprobe analysis carried out on the two samples showed that the average compositional range of plagioclase feldspar can be expressed as An28Ab75 for core composition which indicate andesine to oligoclase. Alkali feldspar expressed asOr86Ab13An1 was mainly microcline to orthoclase. Hornblende in the intrusive charnockite are Mg-rich pargasite while orthopyroxene were mainly hypersthene to ferro-hypersthene in composition. The clinopyroxene is augite. Geothermobarometric calculations using two-pyroxene thermometer show that the crystallization temperature of the intrusive charnockites range from 8060C to 8890C with assumed pressure of 5 kbars suggesting that these rocks are high temperature, low pressure types of charnockitic rocks. The charnockite showed evidence of melting. Dynamic recrystallization of mesoperthitic feldspar and residual alkali feldspar or quartz in biotite relicts are features related to high metamorphic temperatures.

Keywords: Intrusive charnockites, electron microprobe, post crystallization, ductile deformation, low pressure.

1. INTRODUCTION

The word "Charnockite" was first introduced by Holland, (1900) to describe an acid, hypersthene bearing rock of dark appearance to honour Job charnock (founder of Calcutta) whose tombstone was made of the rock. Subsequently, to the novel usage by Holland, (1900), the International Union of Geological Sciences (IUGS) approved the nomenclature. Charnockites are rocks with mineral assemblages that indicate

crystallization under high temperature and medium to high- pressure conditions. They contain orthopyroxene, clinopyroxene, quartz, plagioclase and alkali feldspars, in some cases garnet and opaque ores (Haslam, 1989; Kilpatrick and Ellis, 1992; Thomas et al., 1996; Grantham et al., 1996). Occurrence of charnockites in Precambrian terranes globally offered the petrologists a better understanding of crustal evolution (Unnikrishnan-Warrier et al., 1995).

In some cases, charnockitic rocks derived their mineralogy due to prevailing granulite facies metamorphism Howie, (1955), Cooray, (1969), Janardhan et al., (1979) while the unmetamorphosed magmatic charnockites acquired their charnockitic affinity from crystallization of magma under dry source (Olarewaju, 1987; Olarewaju, 1988; Kilpatrick and Ellis, 1992; Dada et al., 1989; Thomas et al., 1996). Charnockitic rocks, though constitute a minor portion of the Nigerian Basement complex but are of petrological interest (Oyawoye, 1961; Oyawoye, 1962; Oyawoye, 1964; Oyawoye, 1965; Cooray, 1972; Tubosun et al., 1984; Ocan, 1990; Ekwueme et al., 1995; Rahaman, 1976; Rahaman, 1988). They occur in the three Precambrian terranes of Nigeria, namely the Northern, Southwestern, and around Obudu Plateau in Southeast Nigeria. Unlike their occurrence within the amphibolite facies country rocks globally, they have also been identified in granulite facies terrains in Nigeria.

In the Southwestern Nigeria basement complex, charnockitic rocks occur in three forms. They are observed to have a strong affinity for granites. In most cases, they occur within the core and edge of granitic rocks. Again, they occur as enclaves within the surrounding gneisses (Rahaman, 1988; Dada et al., 1989). This paper aims at presenting and discussing the data on the mineral chemistry of the intrusive/magmatic charnockites mapped around Ikare, Southwestern Nigeria, this becomes imperative due to shortage of microprobe data on charnockitic rocks outcropping within the granulite facies terrain of Ikare area.

2. GEOLOGY OF IKARE AREA

The primary rock units within Ikare area are pockets of charnockitic rocks, metapelites, quartzite and granites within an essentially gneissic terrain granitic gneisses and grey gneisses (Figure 1). Granite gneisses are more predominant and serve as host to other rock types. Three varieties of charnockitic rocks were mapped during the fieldwork. They are patchy charnockite within gneisses, magmatic/intrusive charnockites and gneissic charnockites. They are dark to dark-greenish in colour and ranged from fine to coarse grained in texture. In terms of their occurrence, patchy charnockites occur as veins, clots obliterating the foliation in the host gneisses, while magmatic/intrusive charnockites occur in bouldery forms (as seen at Ajowa village, NE of Ikare; Figure 2) and sometimes as low-lying outcrops. Coversely, gneissic charnockites form hills around Erusu through Ikeram-Ibaram to Akunnu Akoko. The mineral assemblage in these charnockitic rocks are essentially identical.

The minerals are quartz, plagioclase feldspar, alkali feldspar, biotite, hornblende, orthopyroxene ± clinopyroxene ± garnet, while magnetite, apatite, ilmenite, chalcopyrite, zircon serve as accessory minerals. Perthite and anti-perthite feldspars are common in the magmatic charnockite. Bent twin lamellae of plagioclase in the magmatic charnockites indicate ductile deformation under granulite facies metamorphism. Like the gneissic charnockite, they contain numerous myrmekiteintergrowth. Petrographic studies on the rocks showed close association between opaque and pyroxene, probably indicating the role played by the opaque in the pyroxene formation. Apart from the charnockites, the host gneisses contain quartz, plagioclase feldspar. alkali feldspar, biotite, hornblende but devoid of pyroxenes. Accessory minerals are opaques ores. The rocks strike the NW direction and mostly dip west in varying degrees (Figure 1).

Mineral chemistry

Experimental procedure

Analyses of minerals were carried out using electron microprobe analyser- JEOL JSM-6510 fitted with INCA-X-act housed at the Institute of Earth and Environmental Science, University of Potsdam, Germany. The condition under which the instrument was operated was given as voltage of acceleration of 15 KeV and regulated beam current of 15 nA. The electron beams were of 1μm in size. For the purpose of study, nine samples of intrusive charnockites were collected from Ikare town and neighbouring villages located in Southwestern Nigeria (Figure 1). A total of five minerals namely alkali feldspar, plagioclase feldspar, hornblende, orthopyroxene and clinopyroxene were probed at the core and rim for their mineral chemistry.

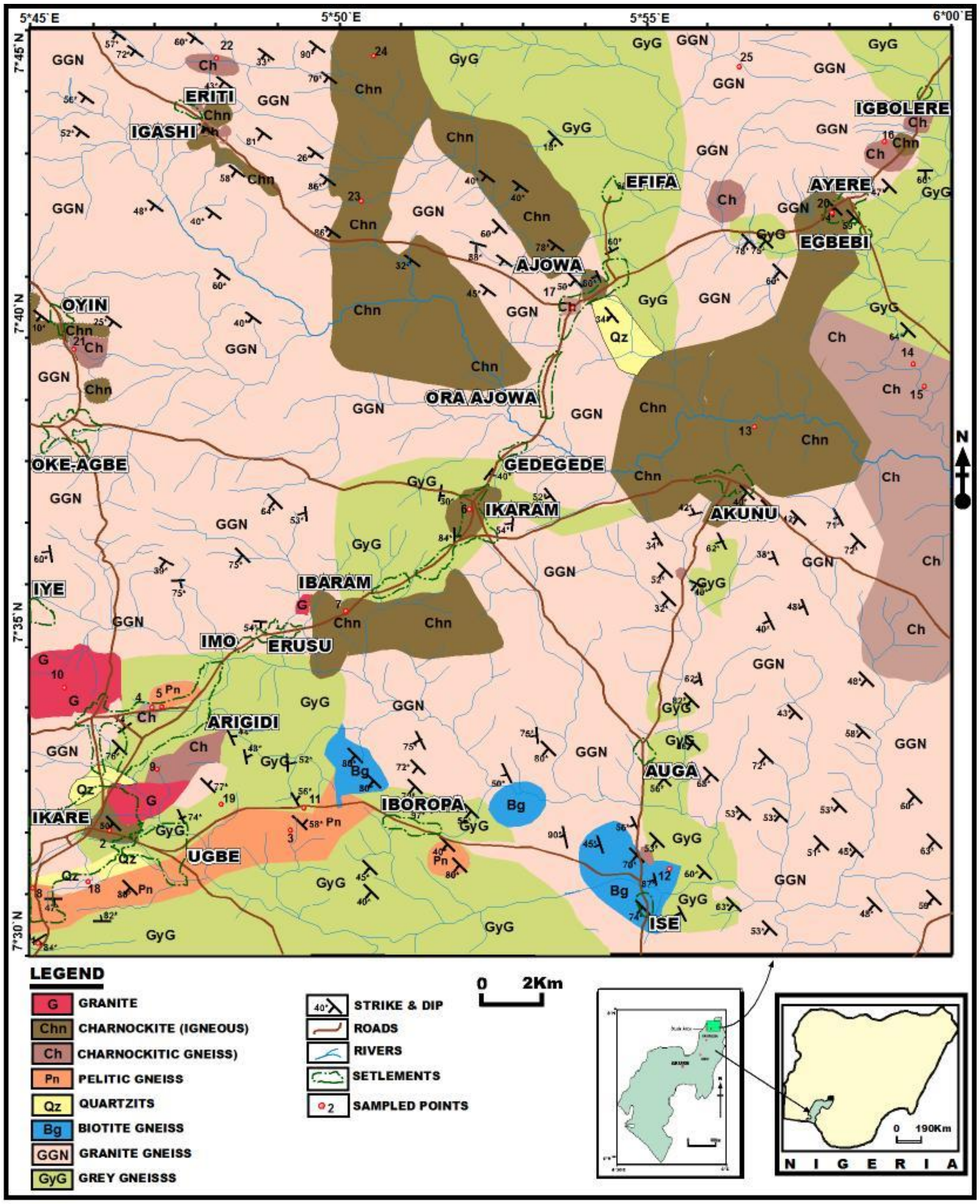

Figure 1 Geological map showing sampling points

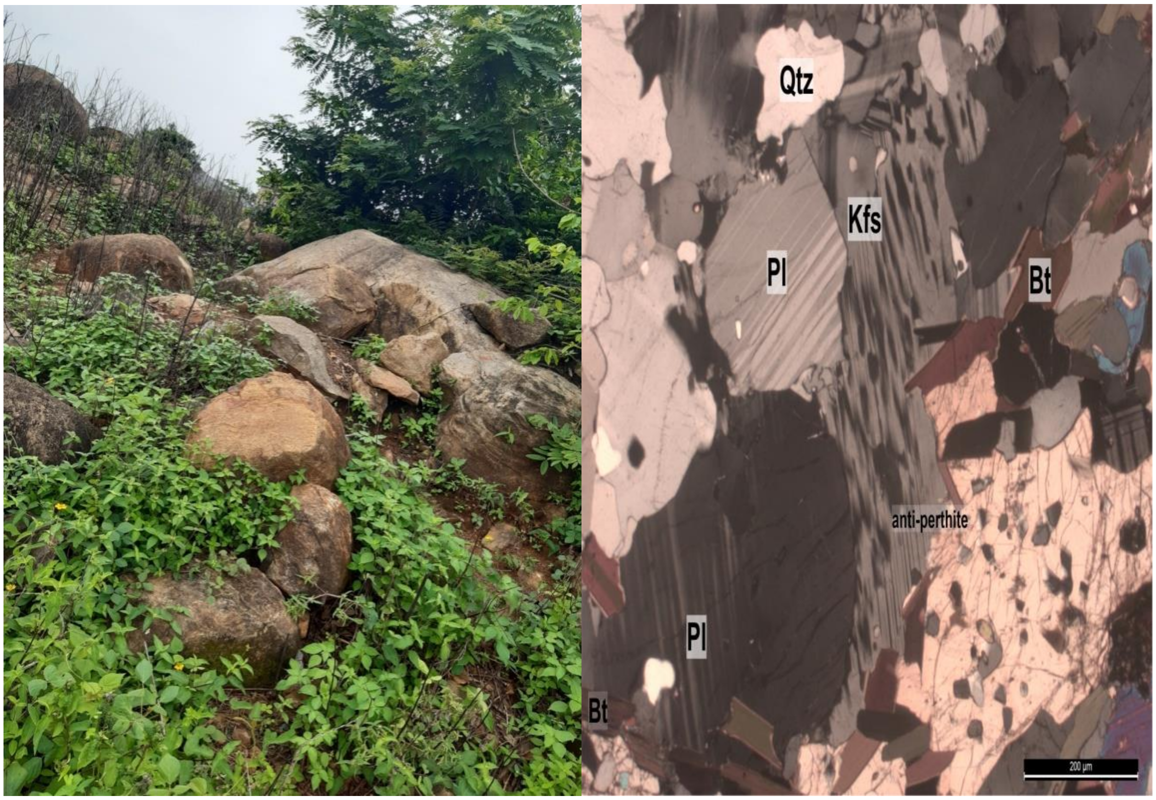

Figure 2 Field photograph showing charnockite at Ajowa, N.E of Ikare town and photomicrograph showing anti-perthite, plagioclase, biotite, quartz and microcline in the charnockite.

3. RESULTS

The results of minerals for the selected rock samples (Ni.15 and Ni.17) are presented in (Tables 1-5). Results of the studies are discussed below.

Feldspars

Feldspars form an important mineral constituent in charnockitic stones. In most of the rocks, feldspars appear as phenocrysts, which often gives a porphyritic texture. The alkali feldspars found in them are both microcline and orthoclase. They show ex-solution or melt mineral textures known as myrmekite intergrowth. Plagioclase feldspars show albite twinning. Anti-perthite textures are also typical in the rocks investigated. The cations were computed on the basis of 8 oxygens. The composition range of plagioclase feldspars in the sampled rocks is expressed as An23Ab76 for the core and An25Ab73 for the rim (Table 1). The chemistry is similar with higher value of Na2O compared to CaO. The anorthite content in the plagioclase is relatively too low, suggesting crystallisation under low activity of water (Rahaman, 1988).

Plagioclase composition range between An32.8 to An17.6 showed andesine tooligoclase (Table 1; Figure 3). Plagioclase from this study give values for CaO (3.76% - 6.82%) and Na2O (7.55% - 9.34%) which is slightly similar to those obtained for plagioclase feldspar in pyroxene granitoid in Piclavesi, Finland (Lahti, 1995; Table 1). The more sodic nature of the samples is reflected in the insignificant amount of anorthite in them. Five representative mineral grains of alkali feldspars were probed. The cations were calculated based on 8 oxygens gives average composition as Or86Ab13An1 at the core (Table 2). On the 2-feldspars diagram, the alkali feldspar from the intrusive charnockite plot in microcline field (Figure 3).

Table 1 Representative microprobe data of Plagioclase Feldspar in the Charnockite (igneous) (Ni.15 and Ni.17)

Oxides (wt%)	core	rim	core	rim	core	rim	core	A
SiO2	60.75	60.15	61.13	59.58	63.02	63.17	62.81	61.15
TiO2	-	-	-	-	0.01	0.01	·	0.00
Al2O3	24.76	25.46	24.89	25.7	23.3	23.2	23.17	23.88
FeO	0.06	-	0.05	0.07	0.04	0.05	0.05	0.04
MgO		-	-	-	-	-	·	·
MnO	0.02	-	0.01	0.02	0.02	0.04	·	-
CaO	5.66	6.44	5.51	6.82	3.97	3.76	3.95	5.56
Na2O	8.22	7.73	8.15	7.55	9.34	9.62	9.21	8.02
K2O	0.37	0.33	0.35	0.24	0.20	0.20	0.10	0.39
Sum	99.82	100.1	100.1	99.98	99.9	100.1	99.29	99.06
Structural formula recalculated based on eight oxygens								
Si	2.70	2.67	2.72	2.65	2.79	2.79	2.79	2.74
Ti	·	-	-	-	-	-	-	-
Al	1.30	1.33	1.28	1.35	1.21	1.21	1.22	1.26
Fe3+	·	-	-	-	-	-	-	-
Ca	0.27	0.30	0.26	0.32	0.18	0.17	0.18	0.27
Na	0.70	0.67	0.7	0.65	0.81	0.82	0.79	0.70
K	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02
End Members (Moles %)								
An	27.2	30.8	26.7	32.8	18.8	17.6	18.9	
Ab	70.7	67.3	71.3	65.8	80.1	81.3	80.0	
Or	2.1	1.9	2.0	1.4	1.1	1.1	1.1	

A = Plagioclase feldspar in pyroxene granitoid in Piclavesi, Finland (Lahti, 1995)

Table 2 Representative microprobe data of Alkali Feldspar in the Charnockite (igneous) (Ni.15 and Ni.17)

Oxides (wt%)	core	rim	core	rim	core	core	core	VO(14)
SiO2	65.28	65.07	65.18	64.68	65.66	65.06	66.12	65.08
TiO2	·	-	-	0.01	-	-	0.02	0.02
Al2O3	18.87	18.75	18.79	18.71	18.77	18.77	18.93	18.20
FeO	0.04	0.01	0.01	0.02	0.01	0.03	0.01	0.01
MgO	0.01	-	0.02	0.02	-	-	0.02	-
MnO	0.01	-	0.01	-	0.01	-	-	-
CaO	0.07	0.06	0.06	0.01	0.01	0.01	0.01	0.06
Na2O	1.36	1.29	1.4	1.17	1.22	1.28	2.05	1.54
K2O	14.74	14.56	14.72	14.69	15.22	14.8	13.9	14.23
Sum	100.36	99.74	100.29	99.32	100.9	99.95	101.06	99.31
Structural formula recalculated based on eight oxygens								
Si	2.99	2.93	2.99	2.99	2.94	2.99	3.00	3.00
Ti	·	-	·	-	-	-	·	-
Al	1.02	1.02	1.02	1.02	1.01	1.02	1.01	0.99
Fe3=	·	-	-	-	-	-	-	-

Ca	·	-	-	-	-	-	-	-
Na	0.12	0.12	0.12	0.11	0.11	0.11	0.18	0.14
K	0.86	0.85	0.85	0.87	0.89	0.89	0.8	0.84
End Members (Moles %)								
An	0.3	0.3	0.3	0.1	0.1	0.1	-	
Ab	12.1	11.8	12.5	10.8	10.8	11.6	18.3	
Or	87.6	87.9	86.7	89.1	89.1	88.3	81.7	

VO (14) = Charnockitic rock along Ikere- Akure road (Olarewaju, 1988)

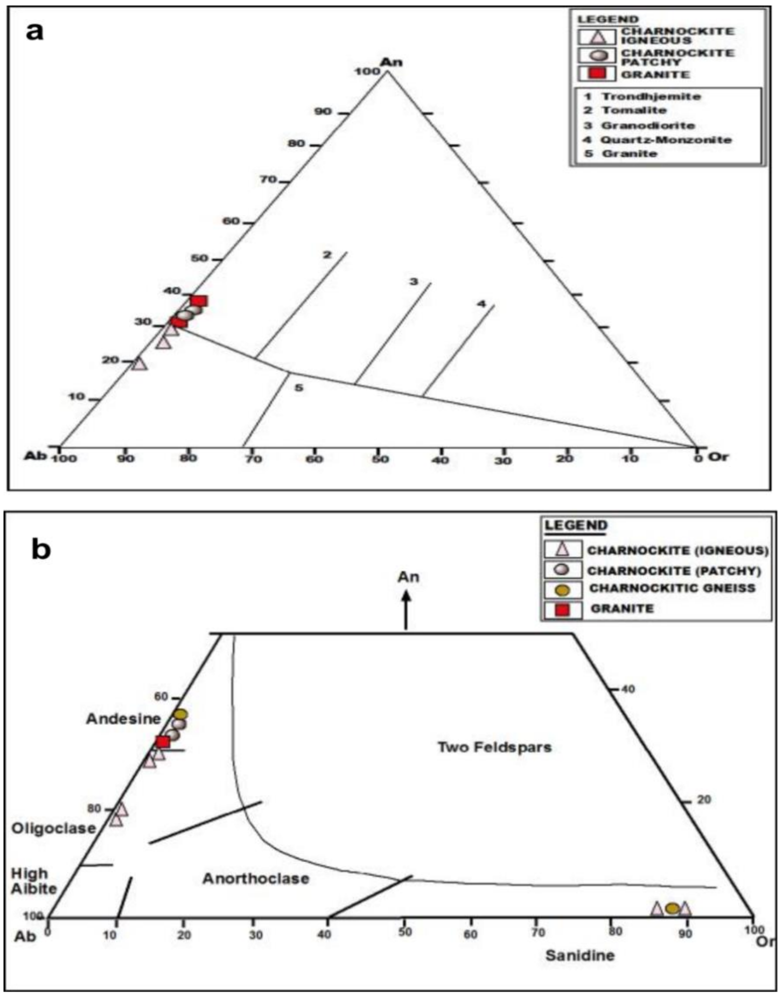

Figure 3 An-Ab-Or ternary diagram showing (a) Plagioclase feldspar plot in tonalite field and (b) Plagioclase range from andesine to oligoclase in composition while alkali feldspar plot as microcline.

Hornblende

Four representative grains of hornblende were probed at the core and rim. The cations calculated on the basis of 23 oxygens. Results are presented in (Table 3). All the hornblende are calcic with CaO range between 10.26% - 10.81% for the core composition which compare favourably with 9.99% obtained for ferro-hornblende syenite from Malawi (Woodley and Jones, 1992). In Table 3, FeO and MgO values vary slightly, with the highest FeO value of 29.50% and the lowest MgO value of 28.79%. For MgO, the highest value of 3.72% and lowest value of 3.08% are relatively lower compared to 5.26% obtained for hornblende in Malawi syenite (Woodley and Jones, 1992).

Hornblende from the magmatic charnockite are Ti-rich (average core composition, 1.96%) above 1.0% suggest that they are primary (igneous) amphiboles and compare favourably those of the Malawi syenite (Table 3).

Table 3 Representative microprobe data of Hornblende in the Charnockite(igneous) (Ni.17)

wt %	core	rim	core	rim	core	rim	core	A
SiO2	39.10	39.1	39.95	38.61	40.05	40.04	39.64	42.17
TiO2	2.18	1.56	1.80	1.74	1.79	1.96	2.09	1.23
Al2O3	10.67	10.5	10.05	10.27	10.11	10.49	10.24	5.96
FeO	29.50	29.1	29.45	28.79	2 9	29.14	29.5	29.23
MnO	0.34	0.44	0.45	0.35	0.39	0.42	0.32	0.72
MgO	3.44	3.39	3.67	3.08	3.72	3.55	3.32	5.26
CaO	10.58	10.62	10.32	10.81	10.26	10.53	10.31	9.99
Na2O	2.08	1.74	2.18	1.91	2.27	1.88	2.18	2.01
K2O	1.55	1.65	1.40	1.87	1.59	1.44	1.45	1.08
Total	99.44	98.10	99.27	97.42	99.13	99.45	99.05	97.82
Structural formula recalculated based on eight oxygens								
Si	6	6.2	6.21	6.2	6.24	6.2	6.15	6.74
Al(iv)	1.91	1.81	1.79	1.8	1.76	1.8	1.85	1.09
Al(vi)	0.05	0.14	0.05	0.14	0.1	0.12	0.02	
Ti	0.26	0.19	0.21	0.21	0.21	0.23	0.24	0.04
Fe3+	0.87	0.86	0.95	0.54	0.83	0.88	1.06	
Fe2+	2.97	2.96	2.88	3.32	2.95	2.9	2.77	3.90
Mn	0.05	0.06	0.06	0.05	0.1	0.1	-	0.09
Mg	0.80	0.79	0.85	0.74	0.86	0.82	0.86	1.22
Ca	1.77	1.79	1.72	1.86	1.71	1.75	1.71	1.66
Na	0.63	0.53	0.66	0.59	0.69	0.56	0.56	0.60
K	0.31	0.33	0.28	-	-	0.28	-	0.21

A = Ferro-hornblende from Malawi Syenite (Woolley and Jones, 1992).

Pyroxenes

Both orthopyroxene and clinopyroxene have been analyzed in sample Ni.15 (Tables 4 and 5). In theWo-En-Fs ternary diagram (Figure 4), the chemical composition of orthopyroxene range from hypersthene to ferro-hypersthene while those of clinopyroxene indicate augite. The composition of CaO (average, 21.41%) compare favourably with 20.40% obtained for clinopyroxene in charnockitefrom Sri Lanka (Table 3).

Geothermobarometry

Numerous thermobarometric calibrations based on compositions of co-existing minerals in charnockitic and other granulite facies rocks have been used for the past many years (Bhattacharya et al., 1991). Estimation of pressure-temperature conditions made on rocks have significant function in the definition of petrogenesis history and regional tectonism. Charnockites contain two pyroxenes which it make more accessible to adopt two-pyroxene thermometry that suit the experimental results on stability of mineral parageneses commonly found in these rocks (Wood and Banno, 1973; Lindsley, 1983; Grantham et al., 1996). Geothermobarometric calculations was done using computer software programmes available at the Institute of Earth and Environmental Science, Universität, Potsdam, Germany. The

computations using 2-pyroxene thermometry of Wells (1977) were done for two samples of igneous charnockite, which were named Ni.15 and Ni.17. Table 6 shows the results.

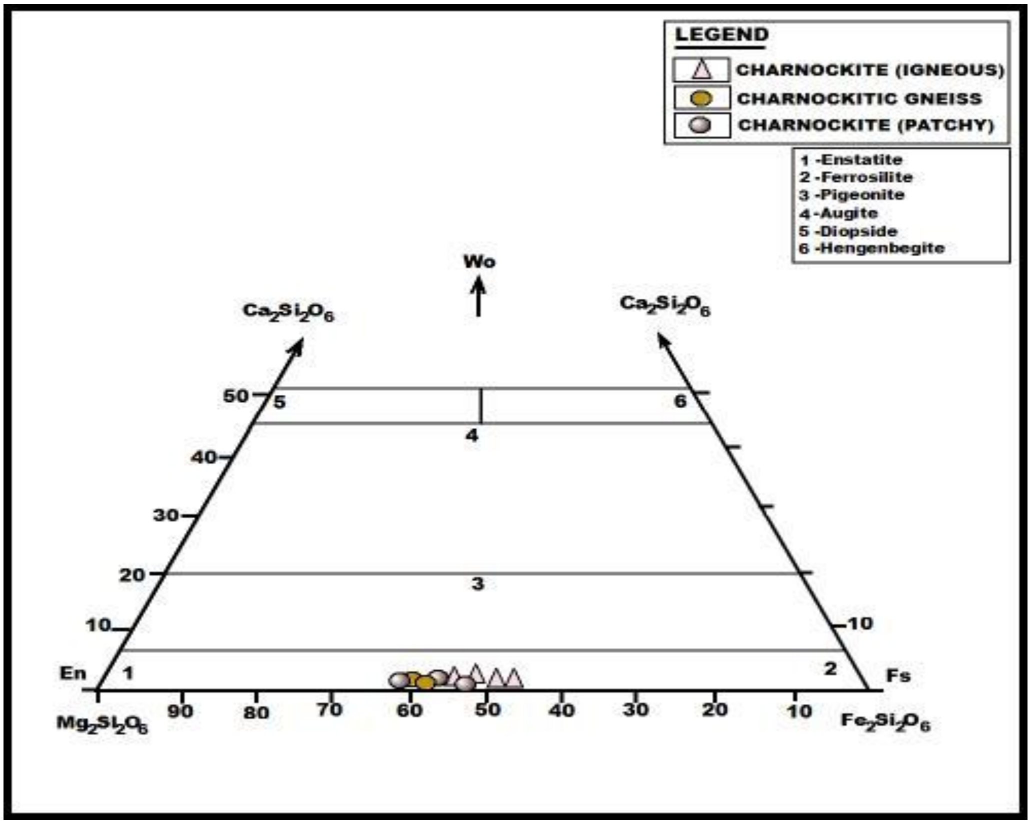

Figure 4 Wo-En-Es ternary diagram showing orthopyroxene plot in hypersthene-ferro-hypersthene fields.

Table 4 Representative microprobe data of Orthopyroxene in the Charnockite (igneous) (Ni.15)

Oxides (wt %)	core	rim	core	rim	core	rim	A
SiO2	50.88	51.08	51.25	51.30	51.13	51.80	47.67
TiO2	0.07	0.11	0.08	0.07	0.09	0.05	0.04
Al2O3	0.39	0.48	0.49	0.46	0.38	0.40	0,26
FeO	29.66	28.70	28.84	28.95	29.45	29.47	44.63
MnO	1.00	0.86	0.94	1.00	1.02	0.99	0.83
MgO	17.03	17.76	17.43	17.08	17.02	17.27	5.37
CaO	0.61	0.92	0.48	1.22	1.14	0.68	0.52
Na2O	0.05	-	-	0.03	0.04	0.03	0.34
K2O	0.02	-	0.01	-	0.02	-	ND
Sum	99.41	99.91	99.52	100.11	100.29	100.69	99.46
Structural formula recalculated based on four cations and six oxygens							
Si	1.97	1.97	1.98	1.98	1.97	1.99	2.00
Al (iv)	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Al (vi)	-	-	0.01	-	-	-	
Fe3+	0.05	0.04	0.01	0.02	0.04	0.01	

Fe2+	0.91	0.89	0.93	0.91	0.91	0.94	1.53
Mn	-	-	-	-	0.03	0.03	0.03
Mg	0.99	1.02	0.93	0.98	0.98	0.99	
Ca	0.03	0.04	0.02	0.05	0.05	0.03	0.02
Na	-	-	-	-	-	-	0.02
K	-	-	-	-	-	-	
End Members (%)							
Wo	0	0	2	2	1	1	
En	51	53	50	50	50	50	
Fs	49	47	48	48	49	49	

A = Orthopyroxene in fayalite-bearing granites, Greenland

ND = Not Determined

Table 5 Representative microprobe of Clinopyroxene in the Charnockite (igneous) (Ni.15)

Oxidewt %	core	rim	core	rim	core	rim	core	rim	core	A
SiO2	51.69	51.93	51.45	52.2	52.19	51.89	51.41	51.69	51.03	51.7
TiO2	0.14	0.12	0.15	0.14	0.16	0.14	0.17	0.15	0.14	-
Al2O3	1.13	0.75	1.28	0.74	1.1	0.98	1.22	1.03	1.54	0.90
FeO	12.43	11.18	13.45	11.11	12.24	11.86	11.87	11.89	12.89	14.70
MnO	0.4	0.38	0.43	0.33	0.44	0.36	0.43	0.38	0.4	0.80
MgO	12.76	12.95	12.56	12.93	12.34	12.63	12.33	12.49	12.37	11.00
CaO	21.43	22.47	20.47	22.91	21.98	22.05	22.06	22.1	21.13	20.40
Na2O	0.43	0.26	0.42	0.29	0.37	0.38	0.38	0.39	0.34	-
K2O	-	0.12	-	0.08	-	0.01	-	0.03	-	-
Sum	98.65	98.99	100.67	100.74	100.82	100.59	99.87	100.15	99.91	99.50
Structural formula recalculated based on four cations and six oxygens										
Si	1.99	1.98	1.95	1.95	1.95	1.95	1.94	1.94	1.93	1.99
Al (iv)	0.01	0.02	0.05	-	0.05	0.04	0.06	0.05	0.07	-
Al (vi)	0.04	0.02	0.01	-	-	-	-	-	-	-
Fe3+	-	0.02	0.07	0.09	0.06	0.08	0.08	0.09	0.09	-
Fe2+	0.4	0.33	0.35	0.26	0.32	0.29	0.29	0.29	0.32	-
Mn	0.01	0.01	0.01	0.01	-	-	0.1	-	-	0.03
Mg	0.63	0.67	0.7	0.72	0.69	0.71	0.69	0.7	0.7	0.63
Ca	0.88	0.92	0.82	0.92	0.88	0.89	0.89	0.89	0.86	0.84
Na	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	-
K	-	-	-	-	-	-	-	-	-	-
End Members (%)										
Wo	46	47	42	46	45	45	45	45	43	
En	33	35	38	40	37	39	38	38	38	
Fs	21	18	20	14	18	16	17	17	19	

A = Clinopyroxene in charnockite from Sri Lanka

Table 6 Estimated pressure - temperature conditions of selected charnockitic rocks

Sample No.	Temperature estimates	Assumed Pressure.
	Two- pyroxene thermometry	
Ni.15	c - 8500C	Five k bars
Ni.17	c - 8890C	Five k bars
		r - 8060C

c -core r- rim

The results showed that the temperature of cystallization of the charnockitic rocks falls between 8500C and 8890C (Table 6). These results agree with 7150C - 9580C obtained for charnockitic rocks of Northern and Southwestern Nigeria by Olarewaju, (1998) also obtained 7600 - 8000C for charnokitic granulites of the Coorg block of Southern India which agree with the obtained crystallization temperatures for Ikarecharnockites. Thermodynamic modeling was done on samples Ni.15 and Ni.2b, using De-Capitani and Petrakasis, (2010) software and 7600C was obtained which is a bit lower compared to 8500C for the core composition (Figure 5). The temperature difference is probably due to retrograde chemical equilibration of the stable mineral paragenesis. Pressure-temperature estimates recorded about 9000C@6 kbar for charnockites of Nagercoil Block in southern India. Grantham et al., (1996) obtained temperatures at about 10000C-11000C for Port Edward enderbite using two-pyroxene thermometry.

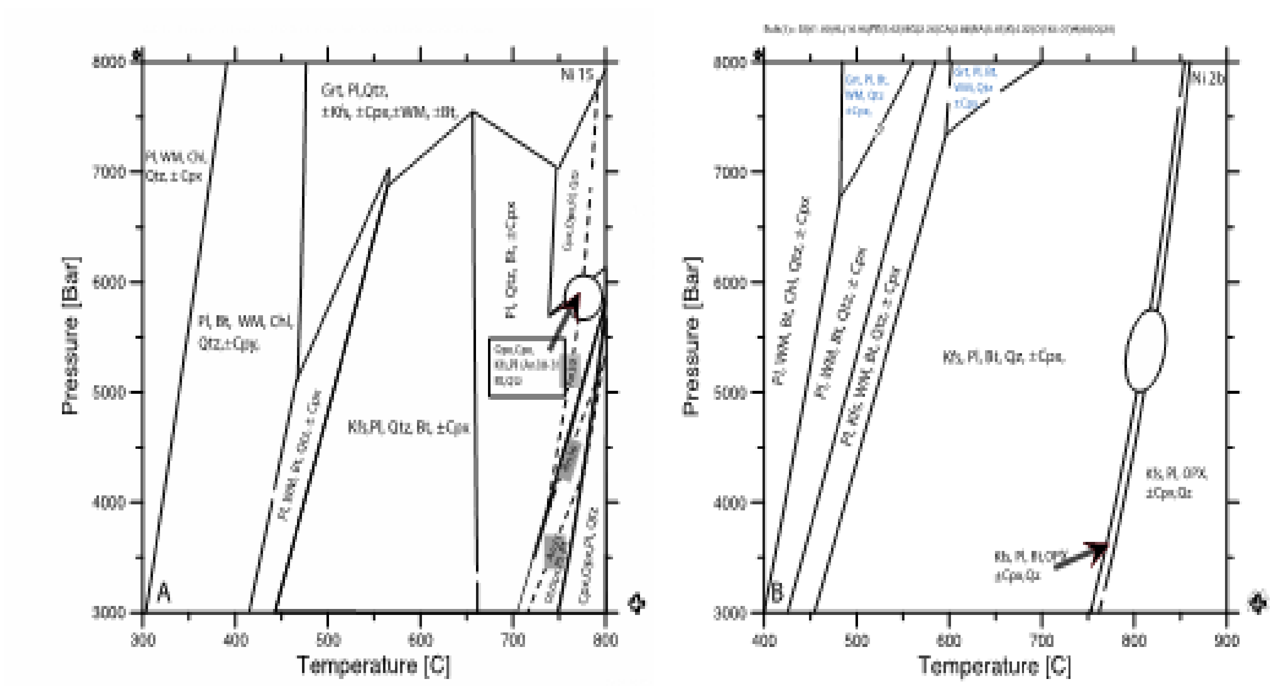

Figure 5 Thermodynamic modeling for igneous charnockites (Ni.15 and Ni.2b) (after De-Capitani and Petrakakis, 2010).

4. DISCUSSION

The charnockitic rocks in the Ikare area, southwestern Nigeria occur within the amphibolite – granulite facies transition zone hosted by high grade rocks of gneisses (grey and granite) and migmatites. In most parts of the world, charnockites are commonly found with metamorphic rocks of granulite facies and anorthosites (Howie, 1955; Cooray, 1969; Condie et al., 1982; Perchuk et al., 1989). Igneous charnockites the Ikare area are typified by metamorphic assemblage consisting of orthopyroxene, plagioclase, alkali feldspar, quartz ±

biotite ± clinopyroxene. The orthopyroxene analyzed in these rocks are iron-rich with up to 60 mol% ferrosilite components, indicating hypersthene compositions. These are typical granulite-facies pyroxene composition. The aluminium content of the samples is below 1.0 apu, indicating low pressure conditions.

Petrographic evidence shows mesoperthitic feldspars and residual alkali feldspars or quartz in biotite relicts, which indicated the melting of the rock. These two features are of metamorphic temperatures. Dynamic recrystallization of alkali feldspars with mesoperthitic texture of the old grains and recrystallized grains is evidence of ductile deformation at high grade, probably granulite facies conditions. This scenario strongly supports the magmatic origin of the igneous charnockites investigated. The model of Dada et al., (1989) suggesting the melting of the lower crustal materials during Pan African thermotectonic event leading to production and upward rise of granitic magma diapirs to higher crustal levels with eventual production of charnockitic magma by fusion under prevailing dry granulite facies conditions is considered appropriate for the magmatic charnockites studied.

The crystallization temperatures of magmatic/intrusive charnockites recorded in this study range of 8500C to 8890C conforms with the range of 7500C- 9500C suggested as crystallisation temperatures for charnockites in depth range 6-30km and pressure range 9-15kbar (Oyawoye and Makanjuola, 1972; Saxena, 1977). Condie and Allen, (1984) had suggested that garnet - free charnockites of Nigeria are of low-pressure type (5-6 kbars). The sampled igneous charnockites are garnet free and therefore of low-pressure type. This is consistent with the estimate of 5 kbars assumed for this study.

5. CONCLUSIONS

Igneous charnockites and the metamorphic charnockites resemble in terms of colours and mineralogy on the field, but the best way to distinguished them lies on the igneous textures observable in them. The igneous charnockites in some cases have strong affinity for granites. Both charnockites contain the same mineral assemblages. Micro-chemical analyses showed that the orthopyroxene in the plutonic charnockites range from hypersthene to ferrohypersthene, but poor in Al (< 0.1apu) characteristics from pyroxene composition in granulite facies rocks.

Some samples show mesoperhitic feldspars (Sample Ni.17) and residual alkali feldspars or quartz in biotite relicts which indicated the melting of the rock. Crustal formation involving production of melts under dry granulite facies conditions of low water activity during the Pan-African orogenic episode is considered for the petrogenesis of the magmatic charnockite in the Ikare area. Crystallization temperature range from 8060C to 8890C with assumed pressure range of about 5 kb corresponding to low pressure charnockites. Ductile deformation after emplacement can be seen in some samples of igneous charnockite in this study.

Acknowledgements

Data used in this paper are parts of the corresponding author PhD thesis. I am grateful to the Tertiary Education Trust Fund (TETFUND) Nigeria for providing fund for this research. I wish to thank Professor UweAlterberger of the Institute of Earth and Environmental Science, University of Potsdam, Germany for his immense contribution and support during the interpretation of the geochemical analyses and computation for geothermometry. I wish to thank both Dr, Daniel Harlov of GFZ, Potsdam and Dr. Christina Günter of the Institute of Earth and Environmental Science, Golm-Potsdam, Germany for their cooperation and assistance in the microprobe analyses.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding
The study has not received any external funding.

Data and materials availability
All data associated with this study are present in the paper.

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